5G Research at Nokia Networks

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CTO of North America
Nokia Networks

5G Day at
MIT Wireless Center
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Outline

- 5G Overview and Requirements
- Air Interface for 5G
  - sub 6GHz
  - cm-wave (6-30 GHz)
  - mm-wave (30-100 GHz)
- Massive MIMO
  - Architecture Options
- 5G Proofs-of-Concept and Demonstrators
- Standards Timeline
- Summary and Next Steps
Nokia Networks – Key facts

- Global market share in telecommunications services: no. 2
- Telecoms experience in years: 100+
- Countries we operate in: >120
- Total public LTE references: 145
- Ranking, macro base station vendor competitive assessment: no. 1
- Global market share in mobile radio: no. 3
- Employees globally: >50,000
- Net sales in 2014: €111.2 bn
The Evolution of Cellular Communications
Higher capacity, lower latency and a more consistent, reliable experience

- Real-time control
- NextGen media
- Monitoring & sensing
- Tactile
- MTC
- Gigabit experience
- Push & pull of technology
5G will expand the human possibilities of the connect world

Throughput
- >10 Gbps peak data rates
- 100 Mbps avg. goodput
- 10-100 x more devices
- M2M ultra low cost
- 10 years on battery
- 10 000 x more traffic

Latency; Reliability
- <1 ms latency
- Ultra reliability

# of Devices; Cost; Power
- A trillion of devices with different needs
- GB transferred in an instant
- Mission-critical wireless control and automation

5G
- Gigabytes in a second
- 3D video – 4K screens
- Work and play in the cloud
- Augmented reality
- Industry & vehicular automation
- Mission critical broadcast
- Self Driving Car

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## 5G technologies under study

<table>
<thead>
<tr>
<th>Deployment</th>
<th>Spectrum access and efficiency</th>
<th>Multi-RAT integration</th>
<th>Radio virtualization</th>
<th>Flexible Networking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Massive MIMO and massive beam forming</td>
<td>3 to 6 GHz: Spectral efficiency (MIMO), &gt;&gt; 6 GHz: path gain and beamforming</td>
<td>5G is integrating novel and existing radio access technologies</td>
<td>Parts of radio will be virtualized, need for specialized L1 HW may still persist</td>
<td>Local gateway/services Per-service tailored feature set (mobility, QoS, latency etc.)</td>
</tr>
<tr>
<td>Centimeter-Wave and Millimeter-Wave</td>
<td>Spectrum access, for dense deployments</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>New waveforms and modulations</td>
<td>Must be justified by gains, compatibility with MIMO essential</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Spectrum access and efficiency**

- Massive MIMO and massive beam forming
  - 3 to 6 GHz: Spectral efficiency (MIMO),
  - >> 6 GHz: path gain and beamforming

**Multi-RAT integration**

- 5G is integrating novel and existing radio access technologies

**Radio virtualization**

- Parts of radio will be virtualized, need for specialized L1 HW may still persist

**Flexible Networking**

- Local gateway/services Per-service tailored feature set (mobility, QoS, latency etc.)

**Reliability - Flexibility - Scalability**
**5G system vision**
A symbiotic integration of novel and existing access technologies

### 5G Wide area deployments
Scalable service experience anytime and everywhere

- **4G** ‘massive mobile data and M2M’
- **3G** ‘voice, video and data’
- **2G** ‘high quality voice and M2M’
- **Wi-Fi** ‘best effort data’
- **Fixed access**

Zero latency and GBps experience – when and where it matters

### 5G Ultra dense deployments

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**For people:**
Ubiquitous connectivity
Consistent high user experience

**Unified solution**

**For operators:**
Tight integration of RATs
Simplified network mgmt
Smooth evolution to 5G
5G radio access to match the available new and old frequency bands

LTE-A will be essential foundation of the integrated 5G system and must continue to evolve in parallel to 5G

A new Radio Access Technology could be motivated by new spectrum allocation (bands above 6GHz), lower latency, or specific use cases.
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- **Air Interface for 5G**
  - 5G < 6GHz
  - cm-wave (6-30 GHz)
  - mm-wave (30-100 GHz)
- Massive MIMO
  - Architecture Options
- 5G Proof-of-Concept (PoC) and demos
- Standards Timeline
- Summary and Next Steps
A new 5G radio interface driven by new technologies and new use cases?
Optimizing access below 6 GHz while enabling access above 6 GHz
Expanding the spectrum assets to deliver capacity and experience

- mm-wave
  - Ultra broadband
  - ~1 GHz carrier bandwidth
  - Dynamic TDD
- cm-wave
  - Enhanced Small Cells
  - Several
  - ~100 MHz carrier bandwidth
  - Dynamic TDD
- < 6 GHz
  - Wide area
  - Up to 100 MHz carrier bandwidth
  - diverse spectrum, FDD and TDD

- Low Rank MIMO\/BF
  - Efficient beam steering
- Higher Rank MIMO & BF
- More noise limited (70-90GHz)
- Strong interference handling
- Full coverage is essential

*) SC = Small Cells

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## 5G PHY Layer considerations

<table>
<thead>
<tr>
<th></th>
<th>LTE rel 13 SI /WI</th>
<th>5G Macro optimized (sub 6GHz)</th>
<th>5G E small cells (cm-wave)</th>
<th>5G Ultra Dense (mm-wave)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spectrum</strong></td>
<td>0.7-3.5GHz (may likely extend)</td>
<td>0.5-10GHz ?</td>
<td>3-30GHz</td>
<td>30-100GHz</td>
</tr>
<tr>
<td><strong>Carrier Bandwidth</strong></td>
<td>1.4-20MHz</td>
<td>~ 5-40MHz</td>
<td>~40-200MHz</td>
<td>~400MHz-2GHz</td>
</tr>
<tr>
<td><strong>Duplex</strong></td>
<td>FDD/TDD</td>
<td>FDD/TDD</td>
<td>Dynamic TDD (full duplex FFS)</td>
<td>Dynamic TDD</td>
</tr>
<tr>
<td><strong>Transmit power DL/UL</strong></td>
<td>&gt;40dBm/23dBm</td>
<td>&gt;40dBm/23dBm</td>
<td>&lt;~30dBm /23dBm</td>
<td>&lt;~30dBm/23dBm</td>
</tr>
<tr>
<td><strong>Waveform UL/DL</strong></td>
<td>OFDMA/SC-FDMA</td>
<td>OFDMA/SC-FDMA *</td>
<td>OFDMA/OFDMA</td>
<td>SC-TDMA/SC-TDMA</td>
</tr>
<tr>
<td><strong>Multiple access</strong></td>
<td>Time &amp; frequency</td>
<td>Time &amp; frequency</td>
<td>Time &amp; (frequency)</td>
<td>Time</td>
</tr>
<tr>
<td><strong>Multi-antenna technology</strong></td>
<td>SU/MU Beamforming and up to rank 8</td>
<td>SU /MU Beamforming and medium rank</td>
<td>SU/MU Beamforming and high rank</td>
<td>SU/MU Beamforming and Low rank</td>
</tr>
<tr>
<td><strong>TTI</strong></td>
<td>1ms</td>
<td>? (flexible)</td>
<td>~0.25ms</td>
<td>~0.1ms</td>
</tr>
</tbody>
</table>

* Other waveforms for massive MTC is FFS
5G below 6 GHz
5G Air Interface for Below 6 GHz
Main technology components

**Top-3 Technology Components**
- Flexible link and air interface
- Advanced Rx/Tx and MIMO
- Native HetNet support

**Unified 5G air interface design for below 6GHz**
PHY numerology, frame design, MAC/RRM is designed to most efficiently support multiple services with different QoS/QoE requirements, including enhanced MIMO and HetNet.

**Advanced non-scheduled access**
- Use of advanced receivers and collision avoidance/recovery protocols for improved massive access performance

**New waveforms**
- E.g. ZT-S-OFDMA to mitigate asynchronous inband/outband interference without need of complex filters

**Flexible frame design**
- Support for different PHY numerologies and TTI sizes to most efficiently carry different services
- Short TTI size for reduced latency

**Advanced MIMO**
- Scalable MIMO from few to many antennas
- adv. interference aware Rx and CSI
- Efficient adaptation between MIMO modes

**Native HetNet support**
- Efficient multi-node coord. And connectivity
- Support for distributed and centralized radio implementations, e.g. remote radio heads.

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**SW demo 2H15**
“flexible link and air-interface” & “advanced Rx/Tx and MIMO”

**SW demo 1H16**
additionally “native HetNet support”
5G in cm-wave bands
Massive MIMO and cm-wave Technology

**Additional capacity**
- Utilization of cm-wave technology together with massive MIMO enables huge capacity increase compared to current deployment - the main source of the gain is additional spectrum.
- This provides credible capacity evolution path for current (macro) operators.
- It will also boost coverage area for higher data rates.

**Massive MIMO**
- Massive (3D) MIMO in at least eNB side compensates the additional propagation loss caused by higher frequencies.
- This can be done with reasonable antenna sizes.

**Possible deployment scenarios**
- Standalone 5G radio (TDD) complementing LTE-Advanced.
- Secondary 5G DL carrier - to be used in combination with LTE-Advanced.

Related 3GPP/LTE scenarios:
- FDD/TDD Carrier aggregation (Rel-12)
- Dual Connectivity (Rel-12)
Capacity and Performance
Example Scenario for Massive MIMO operating @ cm-wave

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrier Frequency</td>
<td>~6 ... ~30 (GHz)</td>
</tr>
<tr>
<td>Frequency band</td>
<td>Unpaired</td>
</tr>
<tr>
<td>Waveform</td>
<td>OFDM</td>
</tr>
<tr>
<td>Multiple access</td>
<td>FDMA/TDMA</td>
</tr>
<tr>
<td>Maximum number of spatial streams</td>
<td>8 – 64</td>
</tr>
<tr>
<td>Maximum number of antennas – eNB</td>
<td>64 – 256</td>
</tr>
<tr>
<td>Hybrid TRX architecture @ eNB</td>
<td>Yes / No</td>
</tr>
<tr>
<td>Maximum number of antennas – UE</td>
<td>4 - 8</td>
</tr>
</tbody>
</table>

**Impact of antenna gain**

<table>
<thead>
<tr>
<th>Carrier Freq.</th>
<th># of Rx antennas required</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.75 GHz</td>
<td>4 (2x2)</td>
</tr>
<tr>
<td>7.5 GHz</td>
<td>16 (4x4)</td>
</tr>
<tr>
<td>15 GHz</td>
<td>64 (8x8)</td>
</tr>
<tr>
<td>30 GHz</td>
<td>256 (16x16)</td>
</tr>
</tbody>
</table>

- These scenarios have similar coverage
- Physical size of the antenna is kept unchanged
One Millisecond Latency

- TTI duration needs to be cut down
- TDD control plane needs to be redesigned
- CTRL and reference signals need to be placed before data in order to allow pipeline processing at the receiver site
- Simple modulation and coding scheme

U-plane latency analysis for UL according to ITU-R M.2134

3GPP LTE-Advanced as part of the IMT-Advanced submission:

<table>
<thead>
<tr>
<th>Delay component</th>
<th>5G</th>
<th>LTE-A TDD</th>
<th>LTE-A FDD</th>
</tr>
</thead>
<tbody>
<tr>
<td>UE Processing</td>
<td>0.25 ms</td>
<td>1 ms</td>
<td>1.5 ms</td>
</tr>
<tr>
<td>Frame Alignment</td>
<td>0.125 ms</td>
<td>1.1-5 ms</td>
<td></td>
</tr>
<tr>
<td>TTI duration</td>
<td>0.25 ms</td>
<td>1 ms</td>
<td>1 ms</td>
</tr>
<tr>
<td>eNB Processing</td>
<td>0.375 ms</td>
<td>1.5 ms</td>
<td>1.5 ms</td>
</tr>
<tr>
<td>HARQ Re-transmission (10% x HARQ RTT)</td>
<td>0.1 ms</td>
<td>1.0-1.16 ms</td>
<td>0.8 ms</td>
</tr>
<tr>
<td><strong>Total Delay</strong></td>
<td><strong>1 ms</strong></td>
<td><strong>6-10 ms</strong></td>
<td><strong>5 ms</strong></td>
</tr>
</tbody>
</table>
## Summary

### Requirements
- 5G cm-wave will meet the challenging 5G requirements
- Main enabler:
  1. Multi antenna systems
  2. Cell densification
  3. New spectrum

### Main technical components
- Simple OFDM-based design with dynamic TDD
- Native massive MIMO support
- Very short frames with cascaded UL/DL control signals
- Very short Hybrid-ARQ cycles

### Integration
- Inter and intra-layer multi-connectivity is essential
- Architecture needs to integrate new and existing radio interfaces
5G in mm-wave bands
**mm-waves: Taking the Pressure Off the Lower Frequencies**

Expanding wireless communications into the outer limits of radio technology

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>Available Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>90-95</td>
<td>2.9 GHz 2 + .09 GHz BW</td>
</tr>
<tr>
<td>70-85</td>
<td>10 GHz 5 GHz BW</td>
</tr>
<tr>
<td>38</td>
<td>4 GHz 50 MHz BW</td>
</tr>
<tr>
<td>28</td>
<td>2 GHz 150/652 MHz BW</td>
</tr>
<tr>
<td>&lt; 6</td>
<td>1 GHz</td>
</tr>
</tbody>
</table>

**Natural evolution of small cells**
- Higher frequency, higher pathloss
- Shrinking cells sizes → mm-wave cellular feasible
- 100-150 meter site-to-site distance
- Dynamic TDD where each slot can be used for DL/UL/Backhaul
- Latency < 1msec

**Permitting high digital data rates**
- **1-2 GHz bandwidth** possible
- **10 Gbps** with 2 Stream, 16 QAM
- **> 100 Mbps** cell edge rates result of noise limited system

**Massive antenna arrays** to overcome propagation challenges
- ≥ 16 element arrays at base station
- **Beamforming** at RF for low power consumption
- **Chip-scale** array elements
- **Over-the-air power** combining provides necessary transmit power
- **Polarization** enables 2 stream MIMO

Technology progress finally makes mm-waves practical to use
Air-Interface Design: Options

- **Air-Interface for mm-wave**
  - Different Options
    - OFDM/ZeT-SOFDM/NCP-SC
  - TDD (Variable DL/UL traffic, Simpler Transceiver)
    - Frame Size = 500 µs
    - Slot Size = 100 µs
    - Downlink/Uplink Interval : Variable
  - Characteristics of ELA @ mm-wave
    - Few users per AP, no need for FDM
    - RF beamforming: avoid multiple users from sharing the same Tx/Rx beam --> loss of beamforming gain
    - Reduce PAPR
  - Example MA technique (Null CP Single Carrier)
    - Null portion enables RF beam switching in the CP without destroying the CP property
    - BW = 2 GHz
    - Data Block Size = 1024
    - Pilot Block Size = 256
- **-Modulation**
  - $\pi/2$-BPSK, $\pi/4$-QPSK, 16 QAM, 64QAM
- **Huge Throughput and Cell Edge gains**
mm-wave – Propagation and Link Budget
First step towards deployment of mm-wave in ultra dense environments

Channel characterization at 73 GHz
Measurements in cooperation with NYU and Aalto University

- Delay spread
  - < 1 ns
  - LOS conditions, narrow beam
  - ~25ns RMS delay
  - spread in non-LOS conditions

- Outage
  - Body loss
  - quite high
  - steerable directional antenna arrays required

- Penetration loss
  - Oxygen/rain
  - not an issue for radius < 200m

- Reflections
  - 3 – 5 reflective paths
  - can be used to establish non-LOS links

- Pathloss
  - 21 dB
  - compared to 5 GHz
  - 29 dB
  - compared to 2 GHz

- Pathloss exponent
  - LOS and NLOS
  - very similar to 3.5GHz band
### mm-wave – Propagation and Link Budget

#### Indoor channel vs. outdoor channel at 73 GHz

<table>
<thead>
<tr>
<th></th>
<th>PLE</th>
<th>STD (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Indoor</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LOS (measured)</td>
<td>1.5</td>
<td>1.0</td>
</tr>
<tr>
<td>LOS (predicted)</td>
<td>1.5</td>
<td>0.8</td>
</tr>
<tr>
<td>NLOS (measured)</td>
<td>3.1</td>
<td>9.0</td>
</tr>
<tr>
<td>NLOS (predicted)</td>
<td>3.1</td>
<td>8.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>PLE</th>
<th>STD (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Outdoor</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LOS B (measured)</td>
<td>2.0</td>
<td>4.2</td>
</tr>
<tr>
<td>LOS B (predicted)</td>
<td>3.5</td>
<td>7.9</td>
</tr>
<tr>
<td>NLOS M (measured)</td>
<td>2.0</td>
<td>5.2</td>
</tr>
<tr>
<td>NLOS M (predicted)</td>
<td>3.3</td>
<td>7.6</td>
</tr>
</tbody>
</table>

**Highlights**

- **PLE STD (dB)**
  - **Indoor**
    - LOS (measured): 1.5
    - LOS (predicted): 1.5
    - NLOS (measured): 3.1
    - NLOS (predicted): 3.1
  - **Outdoor**
    - LOS B (measured): 2.0
    - LOS B (predicted): 3.5
    - NLOS M (measured): 2.0
    - NLOS M (predicted): 3.3

- Smaller RMS delay spread indoor vs. outdoor
- Slightly larger azimuth angle spreads indoor vs. outdoor

**Elevation angle spreads and biases monotonically decrease with distance**

**Azimuth angle distribution: uniform**

(compared to wrapped Gaussian for outdoor)

**Full details in publications (VTC-Fall 2014 and ICNC 2015)**
mm-wave: 5G Requirements Can Be Met Even in Challenging Environments

Performance in outdoor environments
Enabled through
- flexible backhaul
- RFIC/antenna integration

<table>
<thead>
<tr>
<th>AP density</th>
<th>Average UE Throughput</th>
<th>Edge Throughput</th>
<th>Outage Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>75 AP/km²</td>
<td>2.1 Gbps</td>
<td>&lt;1 Mbps</td>
<td>16.4%</td>
</tr>
<tr>
<td>150 AP/km²</td>
<td>4.1 Gbps</td>
<td>222 Mbps</td>
<td>3.2%</td>
</tr>
<tr>
<td>187 AP/km²</td>
<td>5.1 Gbps</td>
<td>552 Mbps</td>
<td>1%</td>
</tr>
</tbody>
</table>

Network capacity
Multi-connectivity
Summary

- **mm-wave Technology can meet the 5G requirements of peak / edge data rates and latency**
  - Well suited for Ultra dense deployments
- **Outdoor and Indoor Channel Models based on measurements and ray tracing**
- **Air Interface Design for 5G mm-wave**
  - Dynamic TDD
  - Simple low PAPR design
  - Per user based control channels with low overhead
- **System level Performance for outdoor and indoor deployments**
  - Meets the 5G peak and edge data rate requirements
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MIMO and massive MIMO will be core technologies in 5G

- In mm-wave bands, most of the spatial dimensions from large antenna arrays will be used to overcome pathloss rather than to provide higher data rates.
- High data rates will be the result of the large bandwidths available at these bands.
- Hybrid/RF (digital & analog) beamforming architecture can be used to reduce the transmitter cost and energy consumption when using massive number of antennas.
- IC technologies suitable for various frequencies is an active area of research together with our suppliers and academic partners.
Massive MIMO provides high gain adaptive beam-forming with antenna arrays

- > 16 antenna ports (e.g. 16, 32, 64, 256 antenna ports)
- Currently a study item in 3GPP for LTE-A
- Phased Array Architecture vs. Band of Operation

**Operator benefits**

- Applicable for both Macro and Small Cells
- Cell edge gain +100%
- Spectral efficiency gain +80%
- Coverage gain to compensate the path loss on high bands making cm and mm waves more practical

**Nokia innovation:**

- mm-wave (70 GHz) PoC system with DoCoMo
- 3D MIMO leader in 3GPP
- Leader in Channel modeling & propagation measurements

**Nokia Research Approach**

- Baseband:
  - 1 transceiver/ant, ~< 6GHz
- Hybrid:
  - $N_{Ant}/B_{RF}$ chains, ~6- 30 GHz
- RF:
  - 1 transcvr/RF beam, >30 GHz

Carrier plate onto which multiple RFIC die are bonded
## Trends for MIMO/BF in 4G and 5G as BW Increases

<table>
<thead>
<tr>
<th>&lt; 6 GHz/low BW</th>
<th>6-55 GHz/moderate BW</th>
<th>&gt;55 GHz/high BW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandwidth Limited</td>
<td></td>
<td>Huge Bandwidths</td>
</tr>
<tr>
<td>Interference Limited</td>
<td></td>
<td>Noise Limited</td>
</tr>
<tr>
<td>Emphasis on Spectral Efficiency</td>
<td></td>
<td>Emphasis on Gain</td>
</tr>
<tr>
<td>Per-antenna channel knowledge</td>
<td></td>
<td>Per-beam channel knowledge</td>
</tr>
<tr>
<td>Baseband Architectures</td>
<td></td>
<td>Hybrid / RF Architectures</td>
</tr>
<tr>
<td>Small Scale Arrays: SU-MIMO sufficient</td>
<td></td>
<td>Large Scale Arrays are required with an initial emphasis on SU-MIMO</td>
</tr>
<tr>
<td>Large Scale Arrays: high-order MU-MIMO</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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Nokia NET 5G demonstrations
Combination of SW and HW demos

cm-wave SW demo

mm-wave SW demo

mm-wave HW demo (73GHz)
mm-wave demonstration scenario
BS synchronization & detection of BS, device tracking, rapid re-routing
### mm-wave Proof-of-Concept: The Essentials

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Frequency</td>
<td>70 GHz</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>1 GHz</td>
</tr>
<tr>
<td>Modulation</td>
<td>Null Cyclic-Prefix</td>
</tr>
<tr>
<td></td>
<td>Single Carrier</td>
</tr>
<tr>
<td></td>
<td>R=1/2 16 QAM</td>
</tr>
<tr>
<td></td>
<td>Single Stream (SISO)</td>
</tr>
<tr>
<td>Antenna Beamwidth</td>
<td>3 degrees</td>
</tr>
<tr>
<td>Antenna Steering Range</td>
<td>34 degrees Azimuth</td>
</tr>
<tr>
<td></td>
<td>8 degrees Elevation</td>
</tr>
</tbody>
</table>

- Access Point
- User Device

- Convergence Conf Room
  (Nokia – Arlington Heights)

- 8 meters
5G technology verification
Nokia is actively engaging with most advanced operators globally to bring 5G to reality

http://blog.networks.nokia.com/mobile-networks/2015/01/16/5g/

https://www.youtube.com/watch?v=EGYkQ5KdKMk
http://networks.nokia.com/videos/ntt-docomo-5g-collaboration
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LTE Evolution and 5G: 3GPP release schedule and topics

- **Rel-13**
  - LAA DL specs
  - LTE CA up to 32 Carriers
  - 3D beamforming/3G beams
  - FD-MIMO specs
  - LTE-M
  - Enhanced D2D V2V / V2X?

- **Rel-14**
  - LAA UL specs
  - Wider BW LTE
  - Shorter TTI
  - CA combos > 100 MHz
  - LTE - Wi-Fi Aggregation
  - LTE optimization up to 6GHz
  - LTE Broadcast only

- **Rel-15**
  - LTE enhancements to meet most of the 5G requirements
    - LAA, dual bands?
  - First 5G version

- **Rel-16**
  - Further LTE enhancements
  - Second 5G version

- **5G requirements SI**
  - Which bands to optimize first?

- **5G technology SI(s)**

- **> 6 GHz channel model SI**

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**3GPP 5G WS**

- WRC-15
- ITU-R 5D technical performance requirements
- 2015
- 2016
- 2017
- 2018
- 2019
- 2020

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5G from research to standards

**Release 13:** Clean LTE-A evolution release
5G research progressing outside 3GPP

**Release 14:** The 5G study phase
leading to Rel-15 work item phase

**Release 15:** The first phase of ‘The Real 5G’;
completion between 2018 and 2020

“5G starts early 2016 in 3GPP with Release 14 and then into Release 15”

“ITU-R processes for IMT2020 run in parallel in close synch”

Note: Future 3GPP release timing uncertain
Outline

- 5G Overview and Requirements
- Air Interface for 5G
  - 5G < 6GHz
  - cm-wave (6-30 GHz)
  - mm-wave (30-100 GHz)
- Massive MIMO
  - Architecture Options
- 5G Proof-of-Concept (PoC) and demos
- Standards Timeline
- Summary and Next Steps
5G Success factors

Summary

1. Pre consensus building among players during explorative research and requirements phases.
2. Global regulatory approach and aim for harmonized spectrum incl. its timely availability.
3. Focused standardization in 3GPP without reducing attention and bandwidth for LTE work.
4. Early sharing of technology feasibility and evaluation results to avoid design at the edge.
**The Nokia way for the 5G Marathon**

“If you want to go fast, go alone but if you need to go far, go together”

<table>
<thead>
<tr>
<th>Outside in 5G</th>
<th>Inside out 5G</th>
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<tbody>
<tr>
<td>• Collaborative research e.g. 5G PPP, 863 5G</td>
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<td>• Customer collaborations</td>
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<td>• Drive regulatory and industry work e.g. ITU-R</td>
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<td><strong>NOKIA</strong></td>
<td><strong>NOKIA</strong></td>
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<td><strong>Collaboration with AT&amp;T on 5G</strong></td>
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<td>• University collaborations e.g. NYU, TUD, Aalto etc.</td>
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<tr>
<td>• Holistic systems research, prototyping &amp; development</td>
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<td>• Leverage One Nokia e.g. Technologies and HERE</td>
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http://networks.nokia.com/innovation/5g